Charging Spin Sequences and Addition Energy of Cylindrical Vertical Quantum Dots

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In atomic physics, Hund's rules constitute a set of heuristic rules that determine the ground state of a N electron system if the electronic configuration is known.

In high symmetry quantum dots, the quantum states are characterized by spatial degeneracy that leads to shell structures in the electronic properties, and Hund?s first rule for partially filled electron shells. These ?atomic ?features are observed in the addition energy spectra of cylindrical-shaped vertical quantum dots, which exhibits maxima for filled and half-filled shells.

We present a detailed analysis of single electron charging effects in cylindrical vertical quantum dots (CVQD). For this purpose we have measured the addition energy spectrum, i.e., the second energy difference or the variation of the electro-chemical potential $\Delta_2(N) = \mu(N+1) - \mu(N)$ as a function of the number of electrons in the dot N of 14 high quality CQDs at 100mK directly from the Coulomb diamonds up to 12 electrons. Emphasis is placed on three-dimensional (3D) device effects that induce appreciable features in the quantized electron spectrum of CQVDs. Our analysis is based on a full 3D self-consistent quantum simulation of single- electron charging in quantized CQVDs by using the density functional theory. In particular, we show that the spin sequences realized in filling the third and fourth electronic shells are a sensitive function of the potential non-parabolicity arising from the 3D CQVD geometry. We also demonstrate that Hund?s first rule can be fulfilled with different maxima in the addition energy spectra. In the third shell, the presence of a minimum at N=7 electrons followed by a maximum at N=8 or 9 electrons, is a clear signature of spin alignment up to mid-shell occupation. Anomalous effects are the result of a subtle interplay between many-body interactions, and the exact shape of the confinement potential that contains 3D components of the nanostructure. Our analysis also shows that spatial degeneracy is not a necessary condition for the fulfillment of Hund?s first rule, in good agreement with experimental data.